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a) Objectives:

The task of the algorithm developing activities at the University of South Florida involves applying optical models of coastal Case II environments and deriving algorithms based on the results of these models. The ability to detect and remove the effects of radiance reflected from the bottom or inelastically scattered from shorter wavelengths due to water Raman or fluorescence is especially important nearshore. Since SeaWiFS will be used as a surrogate for MODIS-N, SeaWiFS algorithm development is our first objective, and an algorithm for chlorophyll a concentration [Chl a] is the first algorithm being developed.

Models of the radiance leaving the ocean are directly dependent upon the back-scattering coefficient and inversely dependent upon the absorption coefficient for seawater. Of these, the absorption coefficient is far more important spectrally for determinations of [Chl a]. The absorption coefficient can be partitioned into the sum of parts due to water molecules, phytoplankton, detritus (includes bacteria), and Colored Dissolved Organic Matter (CDOM). The widely varying CDOM has a profound effect on upwelling radiance in the blue band (443nm) of the CZCS and a smaller but still significant effect in the green band

(520nm). Absorption at these two bands due to excess CDOM creates erroneously high estimates of pigment concentration based upon CZCS radiance-ratio algorithms (see Carder et al. 1991).

Since the absorption coefficient due to phytoplankton (a_{ϕ}) depends on [Chl a] in a non-linear manner due to the pigment-packaging or self-shading effect of phytoplankton, large, highly pigmented cells are less efficient absorbers per unit chlorophyll than are small, slightly pigmented ones (Morel and Bricaud, 1981). We proposed (Carder et al., 1991) that because smaller cells are found in warm, oligotrophic waters and larger cells are found in cold, eutrophic waters, the package effect should vary with season, location, and [Chl a]. Also, models which do not separate absorption due to viable pigments from absorption due to degradation products (DP) of primary production have less utility to researchers applying physiologically based, primary production models or to researchers interested in DP rather than the pigments.

A previously developed semianalytical irradiance reflectance model has been modified to address some of the concerns listed above (Carder et al., 1991). The model was used to develop an algorithm that utilizes a 412nm spectral channel in addition to 443nm and 565nm channels to estimate chlorophyll a concentration and the absorption effects due to DP from irradiance reflectance data.

We are modifying this reflectance model to one using the water-leaving radiance $L_W(\_)$. The algorithm for chlorophyll a and DP must be changed accordingly. A critical concern is the spectral behavior of $E_u(\_)/L_u(\_) = Q(\_)$. This Q factor varies with solar zenith angle and b/c ratio values, and may be affected by viewing angle. A Monte Carlo radiative transfer simulation model for use in evaluating parameters affecting the Q factor is also being developed to compare with measured Q factor. The Q-factor must be either known or predictable to accurately modify our CDOM and chlorophyll a algorithm for use with water-leaving radiance data. Improvements in the empirical relationships for the chlorophyll-specific absorption coefficient as a function of bio-optical provinces are also needed to optimize the algorithm for various seasons and locales (see Carder et al. 1991).

Our primary objective has been to gather field data widely to test the above model and concepts.

b) Accomplishments:

Some of our research has been concentrated on a transect west of Tampa Bay in which highly variable optical constituents were encountered. These included backscattering due to resuspended sediment and absorption due to the gelbstoff of the tidal plume from Tampa Bay. The effects of water Raman, gelbstoff fluorescence, and bottom reflectance were also evaluated for this area. Results from an AVIRIS overflight in March 1990 and accompanying field data resulted in several papers published or submitted for publication. These reports have concentrated on separating the spectral effects of gelbstoff and DP from those of pigments in the presence of bottom reflectance and trans-spectral (inelastic) scattering.

The TAMBAX-II cruise from May 11, 1992 to May 13, 1992, was conducted in the Eastern Gulf of Mexico in conjunction with an overflight of the Airborne Oceanographic Lidar (AOL) of Dr. Frank Hoge. Samples inside Tampa Bay were also taken coincident with the overflight using a small boat. The NASA P3 aircraft from Wallop's Island AFB overflew the cruise, operating the AOL and microwave radar to sample fluorescence, and water salinity. On board the R/V SUNCOASTER of the Florida Institute of Oceanography (FIO), samples for chlorophyll-specific absorption and gelbstoff absorption coefficients, remote sensing reflectance, salinity, bottom albedo, sediment-column chlorophyll a, and water-column chlorophyll a were taken.

Data from this cruise have been worked up to test the pigment package model algorithm presented in Carder et al. 1991. The model algorithm, "tuned" to the field data, well represented the spring data for this subtropical environment, with only an 11.3% error (Fig. 1) for the pigment range encountered (0.08 < [Chl a] < 1.0 mg/m^2). As species succession changes cell size over the year, and light and nutrient stress play roles affecting intracellular pigment concentration and composition, this curve is expected to change. How well we can eventually predict or monitor these changes will determine the limiting accuracy for calculating [Chl a] from SeaWiFS and MODIS-N data. As of now, satellite-derived accuracies significantly better than 15% are unlikely since the satellite effectively is measuring absorption, not [Chl a], and algorithms such as in Fig. 1 with this order of error are required to convert phytoplankton absorption coefficients into [Chl a]. Th results were presented at the SeaWiFS/MODIS team meeting, October 25, 1992, at UCSB and at the Western AGU in San Francisco (Carder et al., 1992c).

A method to calibrate the AVIRIS data based on water leaving radiance measurements and atmospheric corrections using LOWTRAN-7 program elements, has been developed, and a paper describing the methodology has been accepted for publication (Carder et al., in press a). This method permits aircraft-measured radiance data to be merged with in situ field data to serve as a tool for satellite algorithm development and testing. The AVIRIS sensor has better than 10nm spectral resolution in the visible from 400-1000nm and can be used to simulate HIRIS, MODIS-N, and SeaWIFS data by spectral and for spatial pixel binning. This also helps improve S/N which is probably 4x to 6x less than expected for HIRIS on a single-pixel basis.

AVIRIS data from Tampa Bay and Lake Tahoe together with our supporting in situ data were used in the last several months to refine our reflectance model for quantifying chlorophyll a in Case I and Case II waters. The effect of bottom reflectance was apparent for many of these coastal data sets. The effect of water Raman, gelbstoff fluorescence and bottom reflectance contributed as much as 20% of the signal even for water depths as deep as 25m. The Raman and fluorescence signals were predicted with reasonable accuracy, and the bottom albedo was estimated by providing a best-fit of modelled-to-measured results (see Lee et al. 1992, Lee et al. submitted).

A paper which provided the fluorescence efficiency curves needed to model CDOM fluorescence was also presented in the same meeting (Hawes et al., 1992).

On November 17, 1992, we conducted an AVIRIS Experiment in Florida after Hurricance Andrew. Two transects over the Upper Florida Keys and Key Biscayne were flown by the AVIRIS team. The transects extended from beyond the outer reef in Florida Current waters to Hurricane Andrew-damaged mangrove areas of the mainland. On the return flight from the Keys to Tindall AFB in north Florida, AVIRIS data were collected along the west coast of Florida from Florida Bay in the south to Apalachee Bay in the north. Two surface vessels were deployed during the overflight with researchers from the University of South Florida, Jet Propulsion Laboratory, Florida Marine Research Laboratory, and Key Largo National Marine Sanctuary. One vessel collected samples along the transect in the Keys, the other collected samples crossing the return transect at Tampa Bay. Atmospheric solar transmissivity was measured with a Regan radiometer (JPL-supplied) at a site on Tampa Bay. Measurements taken to support the flight included water-leaving radiance, downwelling irradiance, chlorophyll concentration, absorptions due to chlorophyll, gelbstoff, and detritus, and fluorescence efficiency of gelbstoff.

We have estimated the bottom albedo from remotely-sensed data by comparing modelled depths to bathymetric chart data and adjusting the albedo until a match is reached. Generic spectral albedo curves for sands from the West Florida Shelf have been determined for a few, diver-retrieved and core samples for comparison with model results. We consider that the model results found so far are very reasonable, however significantly more bottom albedo measurements are needed to ensure closure between modelled and measured results. The bottom sediments contained 6x-20x the pigment/cm^2 found in the overlying water column in the summer and a very sharp decrease in the albedo at 675 nm was found accordingly for pigment rich sands.

A method was also developed by using model inversion of AVIRIS data to estimate the gelbstoff-absorption coefficient for the Tampa Bay plume, and a salinity-gelbstoff curve provided a means of mapping the surface salinity distribution for the region using AVIRIS-derived gelbstoff-absorption data (Carder et al. in press b).

At the western AGU meeting, December 7, 1992, in San Francisco a paper was presented that provided algorithms for calculating the absorption and the diffuse attenuation coefficients of surface waters for use with aircraft sensors flying near the sea surface during sunny and overcast conditions. These new algorithms provided estimates with correlation coefficients of 0.98 and accuracies better than + 10%.

CZCS data from the Pacific showing covariance between mineral depositional cross-sections and aerosol radiance, and between aerosol iron-fraction and [1.0 - E(550,670)] were presented at the MODIS/SeaWiFS meeting in Santa Barbara, and a subsequent paper has been submitted for publication(Young et al., submitted). These data suggest that the "clear-water" radiance approach to discriminating iron-rich aerosols with SeaWiFS and MODIS-N may be used between + 30 degrees and -30 degrees latitude, except near continents and at the equator. These data were collected at 26^0 N and 155^0 W in early spring of 1986, and dissolution of only 10% of the aerosol-iron could have supported the increased production observed, based upon stoichiometric considerations (Young et al., 1991).

We have also been considering algorithms for bathymetry using AVIRIS data and field measurements from Lake Tahoe and the west Florida shelf. These can be used for several purposes: 1) measure bathymetric changes due to hurricanes or other sediment transport mechanisms, 2) define where and when chlorophyll and CDOM algorithms will be affected by bottom reflectance, 3) correct or modify algorithms to perform adequately in the presence of bottom-reflected radiance, 4) map sea grass or algal beds and monitor their changes. The second and third purposes are directly pertinent to algorithm performance for the relatively clear shelf waters of most subtropical/tropical shelves.

c) Anticipated Activities:

The bottom albedo is needed to perform accurate bathymetry calculations, to determine water clarity, and estimate chlorophyll content in shallow waters using passive remotely sensed data. A new Spectral Upwelling and Downwelling Sensor (SUDS) is being developed with NASA Core program funding, which will be useful in measuring/confirming bottom albedo curves during future cruises. It has 2nm spectral resolution and .6 nm sampling intervals. The effects of bottom reflectance will be incorporated into the model for Case II waters, and algorithms for chlorophyll a calculations will be evaluated in terms of the error that is induced by bottom reflectance.

d) Problems/Corrective Actions:

None of note

e) References:

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3. Carder, K.L., R.G. Steward, R.F. Chen, S.K. Hawes, Z. Lee, C.O. Davis, AVIRIS Calibration and Application in Coastal Oceanic Environments: Tracers of Soluble and Particulate Constituents of the Tampa Bay Plume, Proceedings of First Thematic Conf. on Remote Sensing for Marine and Coastal Environments, New Orleans, 1992.

4. Lee Z., K.L. Carder, S.K. Hawes, R.G. Steward, T.G. Peacock, C.O. Davis, An interpretation of high spectral resolution remote sensing reflectance, Ocean Opitics XI, Proc. SPIE 1705: in press.

5. Lee Z., K.L. Carder, S.K. Hawes, R.G. Steward, T.G. Peacock, C.O. Davis, A model for interpretation of hyperspectral remote sensing reflectance, Applied Optics, 1992, submitted.

6. Morel, A. and A. Bricand, 1981, Theoretical results concerning light absorption in a discrete medium, and application to specific absorption of phytoplankton, DSR, 28A(11), 1375-1393.

7. Young, R.W., K.L. Carder et al., 1991, Atmospheric Iron Inputs and Primary Productivity: Phytoplankton Responses In the North Pacific, Global Biogeochemical Cycles, 5(2): 119-134.

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f) Published and submitted manuscripts:

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2. Carder, K.L., R.G. Steward, R.F. Chen, S.K. Hawes, Z. Lee, C.O. Davis, AVIRIS Calibration and Application in Coastal Oceanic Environments: Tracers of Soluble and Particulate Constituents of the Tampa Bay Plume. Photogram. Engr. & Remote Sensing, in pressed b.

3. An interpretation of high spectral resolution remote sensing reflectance, Ocean Opitics XI, Proc. SPIE 1705: in press.

4. Hawes, S.K., K.L. Carder, G.R. Harvey, 1992, Quantum Fluorescence Efficiencies of Marine Humic and Fulvic Acids: Effects on Ocean Color and Fluorometric Detection, Ocean Opitics XI, Proc. SPIE 1705: in press.

5. Hawes, S.K., K.L. Carder, G.R. Harvey, Quantum Fluorescence Efficiencies of Marine Humic and Fulvic Acids, Proceedings of First Thematic Conf. on Remote Sensing for Marine and Coastal Environments, New Orleans, 1992.

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8. Lee et al. Lee Z., K.L. Carder, S.K. Hawes, R.G. Steward, T.G. Peacock, C.O. Davis, Ax Model for interpretation of hyperspectral remote sensing reflectance, Applied Optics, 1992, submitted.

g) Theses Relevant to MODIS/HIRIS:

1. Peacock, T.G., Some Marine Light Sources and Their Effects on Remote Sensing Reflectance Models, 1992.

2. Hawes, S.K., Quantum Fluorescence Efficiencies of Marine Fulvic and Humic Acids, 1992.